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EMISSION OF PARTICLES FROM A CHARGED SPHERE INTO A MAGNETIC FIE--ETC(U)

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Emission of Particles From a Charged Sphere Into a Magnetic Field. Part II

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FOR THE COMMANDER

John Harwood

Chief Scientist

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Trajectories of particles emitted normally from a charged sphere into a constant magnetic field are examined. Corrections are made to previous calculations which led to the separation of such trajectories into two classes, those which return to the sphere and those which do not.

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Preface

I thank Pat Bench for programming the numerical solutions.

Emission of Particles From a Charged Sphere Into a Magnetic Field. Part II

This report is Part II of a study that discusses the emission of charged particles from a charged sphere into a constant magnetic field. In particular, the previous paper[1] presented a number of curves that separate such particles into those which are returned to the sphere and those which are not. These curves plotted β, a non-dimensionalized initial momentum of the emitted particle vs. θ, the angle made between the initial direction of emission and the magnetic field. A series of such curves was shown, each one characterized by two parameters specifying the nature of the potential around the sphere. This latter was assumed to have a form $\phi = \phi_0 \frac{1}{r^N}$ where r is a radial coordinate, and the two parameters were α, a non-dimensionalized form of the sphere potential, ϕ_0, and N which specifies a power law for the potential.

The procedure, as described in Part I, used to find the separation curves was as follows. Starting with a value of $\theta \approx \pi/2$ which guarantees a return, trajectories were taken for values of θ successively decreased by 0.05 radian until an escape was obtained. Starting with this value of θ, trajectories were taken for values of θ successively increased by 0.005 radians until a return was obtained. This process was continued until the desired accuracy of the value of θ corresponding to the given α, β, and N was attained.

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1. Sherman, Christopher (1980) J. Appl. Phys. 51:1294

Since we are dealing with numerical solutions, it is clear that, in general, any criterion as to when to terminate a given trajectory and count it as an escape must be arbitrary. The original paper used escape (termination) criteria which were not, in many instances, stringent enough, and this resulted in appreciable errors in the curves. In the present paper we impose more stringent escape criteria and also make these criteria explicit. The calculations are thus improved substantially; but along with this improvement certain ambiguities arise which we have not been able to resolve.

If the escape criteria are based on trajectory properties, two distinct termination criteria are needed. First, we count all particles which have exceeded a specified radius as having escaped. Because of the cyclotron motion induced by the magnetic field, however, particles can perform many cyclotron orbits while remaining close to the sphere, and this type of motion necessitates a second termination criterion. The number of cyclotron orbits in a given trajectory can be counted, and particles which have exceeded a specified number of cycles may also be counted as having escaped. For the present paper, the escape criteria radius, $R_{LIM} > 1000 r_o$ (r_o = initial particle radius) and cyclotron orbits, $\Omega_{LIM} > 500$ were chosen. These conditions are considerably more stringent than those imposed in the original calculations, and they result in separation curves that differ appreciably from the original curves.

Figures 1 and 2 show the results of the new calculations, along with the curves from the original paper for N=1 and various values of α. Also shown for the smaller values of α are several high magnetic-field limits. In this limit the cyclotron orbits are so small that we may invoke a conservation of energy law for the component of the initial velocity parallel to the magnetic field. These curves are thus plots of the relationship

$$\beta = \frac{\sqrt{2\alpha}}{\cos\theta} \quad . \tag{1}$$

For values of $\alpha < 0.1$, the calculated curves approach the high field limits fairly closely.

For $\alpha \geq 1$, many of the calculated points seem to show an irregular scatter; hence, complete curves are not drawn in for all values of $0 \leq \theta \leq \pi/2$. The question raised by these scattered points is whether they represent genuine details of structure, errors introduced by the method of calculating the separation trajectories, or a combination of the two. The evidence we have bearing on this question seems to be ambiguous. The fact that the scatter arises for some values of α and not for others argues for it being genuine; that the separation curves must be continuous functions of initial conditions would seem to indicate

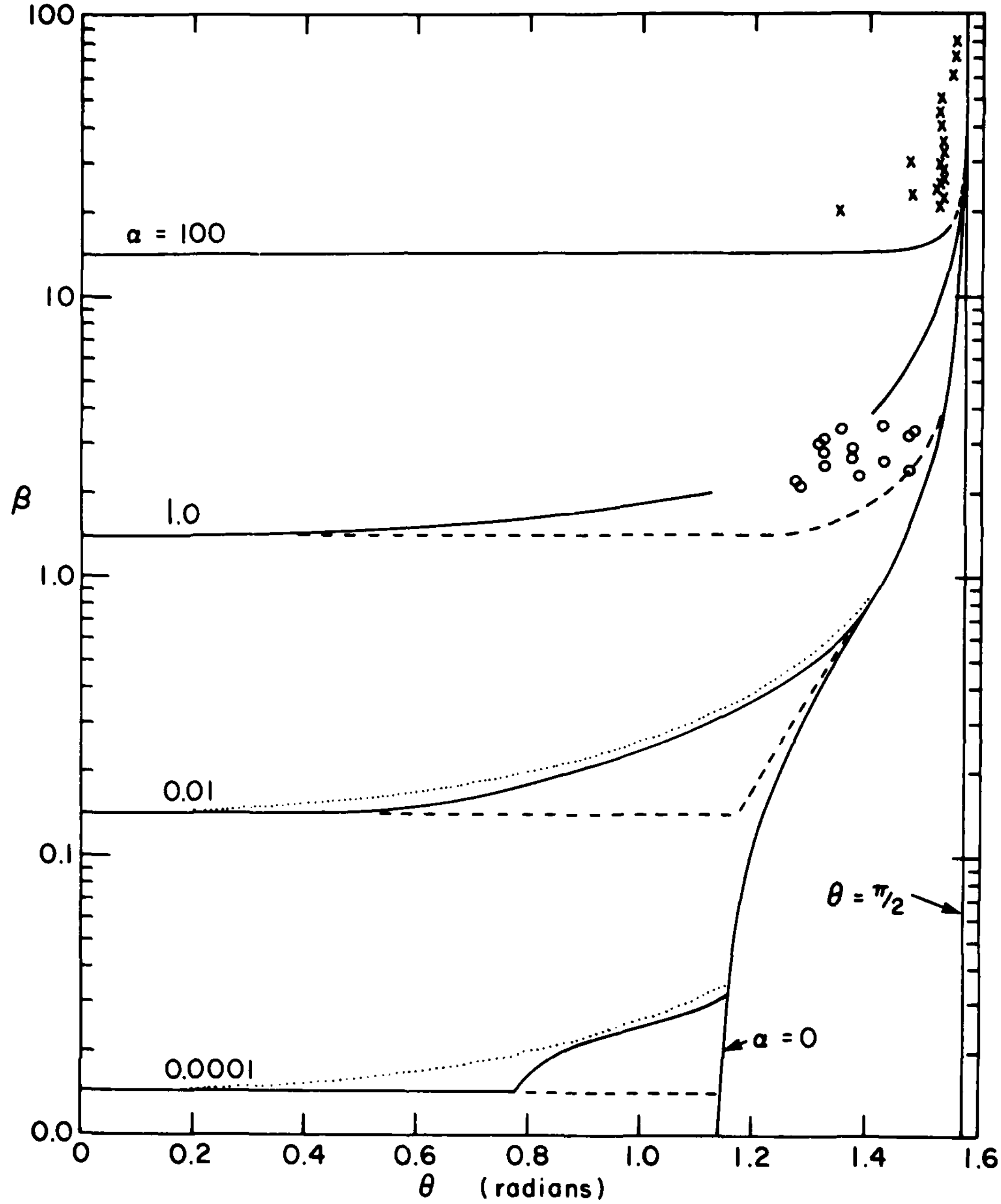

Figure 1. Separation data for N=1 and four values of α. Solid lines, present calculations; dashed, previous calculations; dotted, high magnetic field limit; circles and crosses, scattered values for α = 1.0 and α = 100 respectively

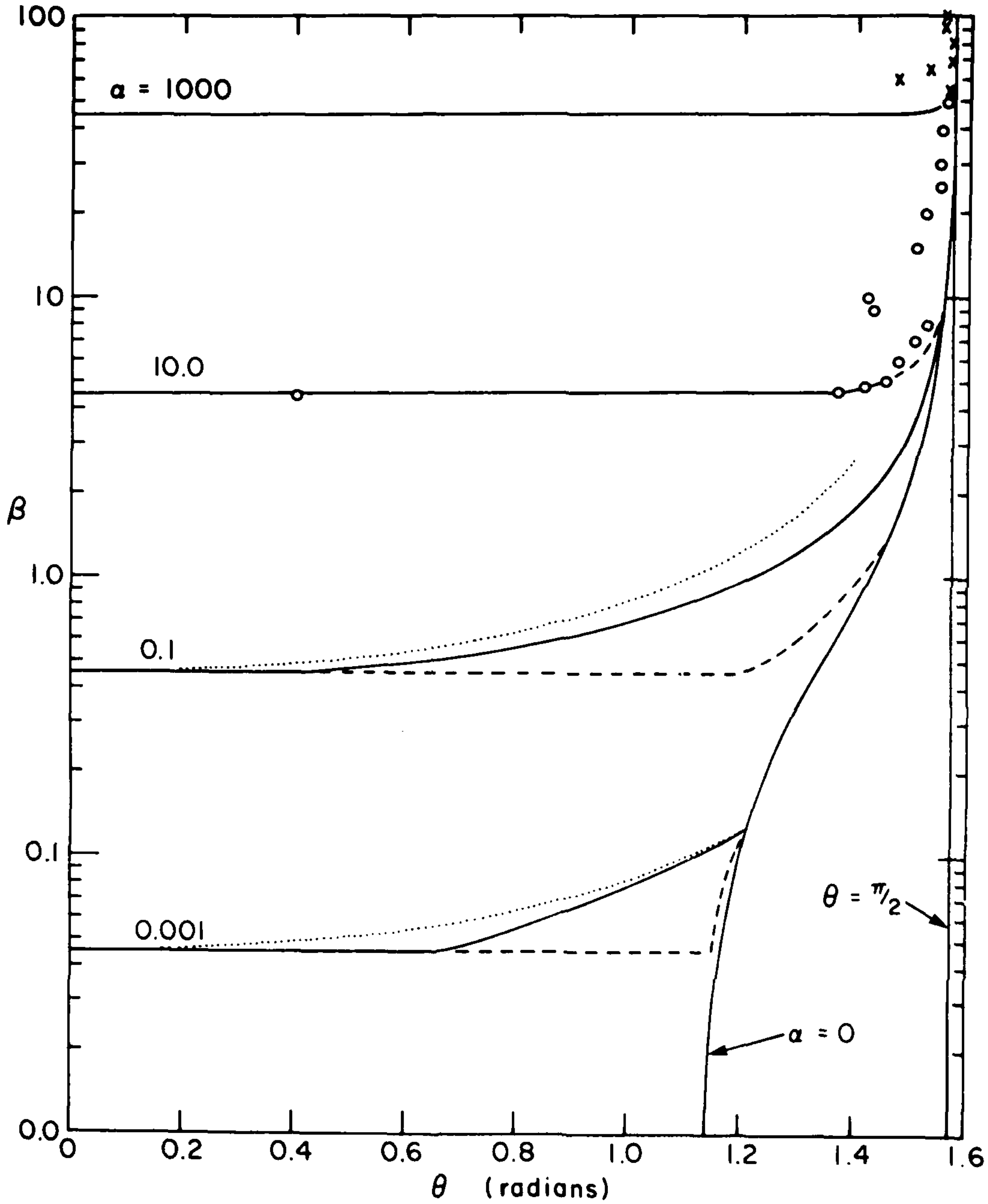

Figure 2. Separation data for N=1 and four values of α. Solid lines, present calculations; dashed, previous calculations; dotted, high magnetic field limit; circles and crosses, scattered values for α = 10 and α = 1000 respectively

(unless there is very fine structural detail) that the scatter is due to computational procedures. Increasing the values of R_{LIM} and ρ_{LIM} for all scattered points would require excessive demands on machine time; increasing these limits for several points chosen within a narrow range of values of ρ did not change calculated values of θ, but for one point also within this same range, it did. We note that if the scatter is due to inadequate values of R_{LIM} and ρ_{LIM}, increasing these limits can only lead to lower values of θ, making the calculated values of θ upper limits. The displacing of all scattered points to lower values of θ would not, in all cases, make it possible to connect them with curves which would join smoothly to the portions of continuous curves already present. The cause of these scattered values thus is not certain.

As explained in the earlier paper, the calculations for values of $N > 1$ are made to simulate the effects of ambient space charge. Figures 3, 4, and 5 show the results of the separation calculations for five value of N, and for the three value of α = 0.01, 1.00, 100, respectively. Also shown on each of these figures is a "thin sheath limit." This is obtained by plotting θ, as taken from the α = 0 separation curve, as a function of $\rho' = \sqrt{\rho^2 - 2\alpha}$. Scattered values again appear for γ = 1.0 and γ = 100, but only for the lower values of N. The appearance of these scattered values for the lower values of N only, again argues for their validity, while continuity arguments indicate the reverse. In the cases for which smooth curves can be drawn, they form monotonic sequences which approach the thin sheath limit with increasing N; and, further, the scattered values also generally seem to have higher values of θ for higher N, for ρ fixed. This behavior, which is what one might expect, was not found in the equivalent curves of the original calculations. The basic conclusion of the original paper, however, is still valid; unless angles of emission are quite high, particles having energies above the sphere potential have a good chance of escaping.

For those values of γ or N which result in smooth curves, the present calculations represent a definite improvement over the original ones. The cases for which scattered values arise, on the other hand, raise questions which require further work to answer.

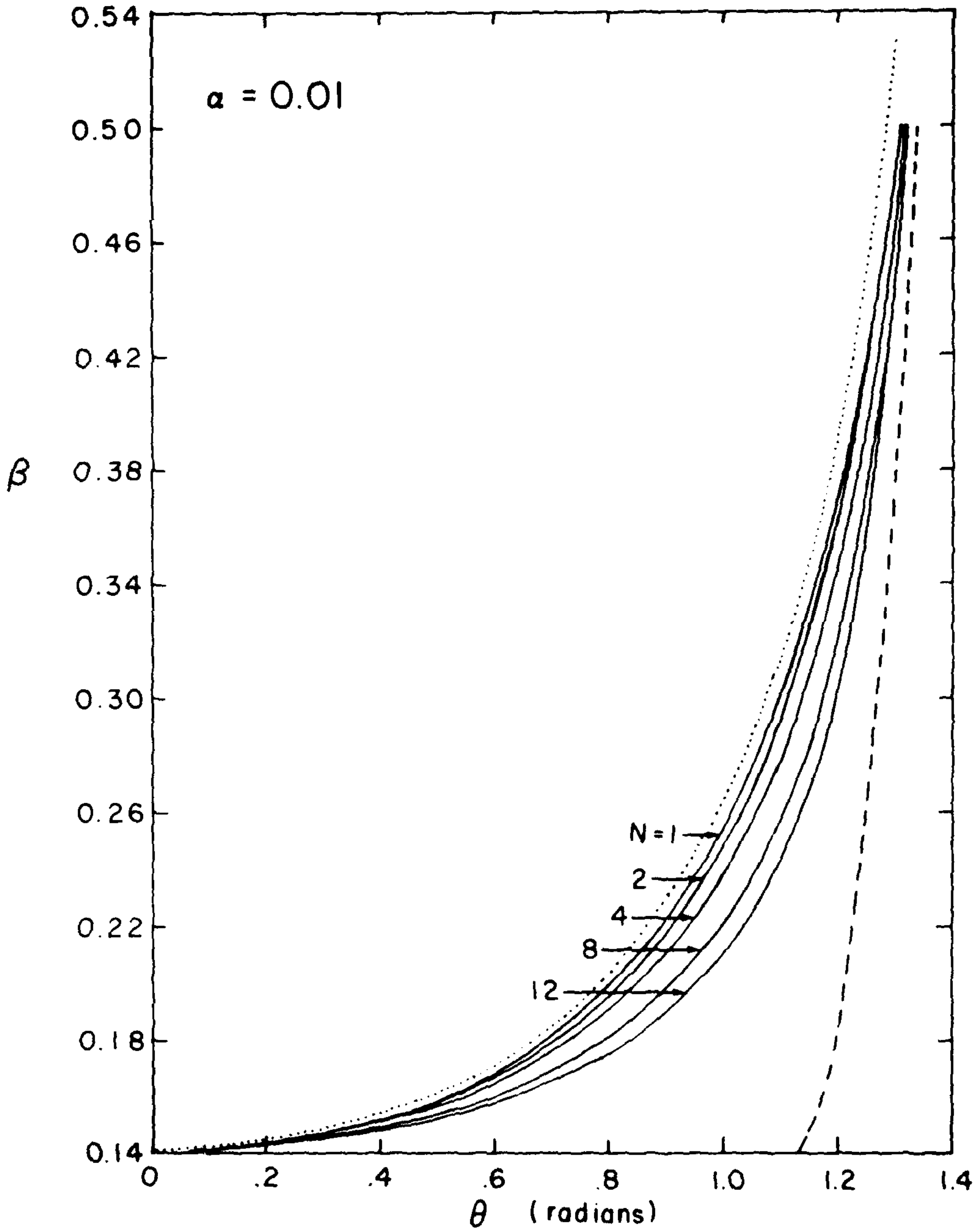

Figure 3. Separation curves for $\alpha = 0.01$ and five values of N. Dotted curve, high magnetic field limit; dashed, thin sheath limit

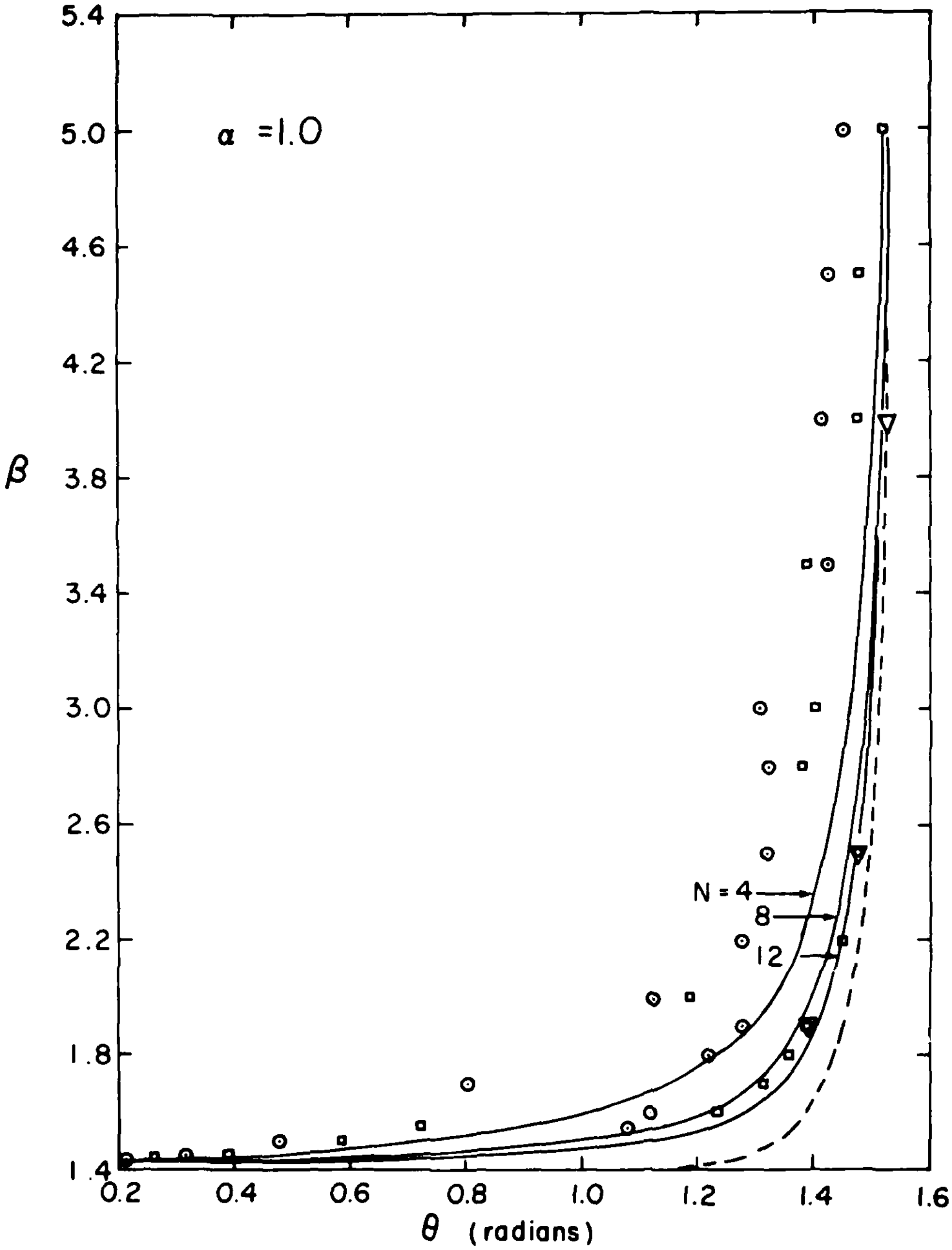

Figure 4. Separation data for α = 1.0 and five values of N. Solid curves, N=4, 8, 12; Circles N=1, squares N=2, triangles N=4; dashed curve, thin sheath limit

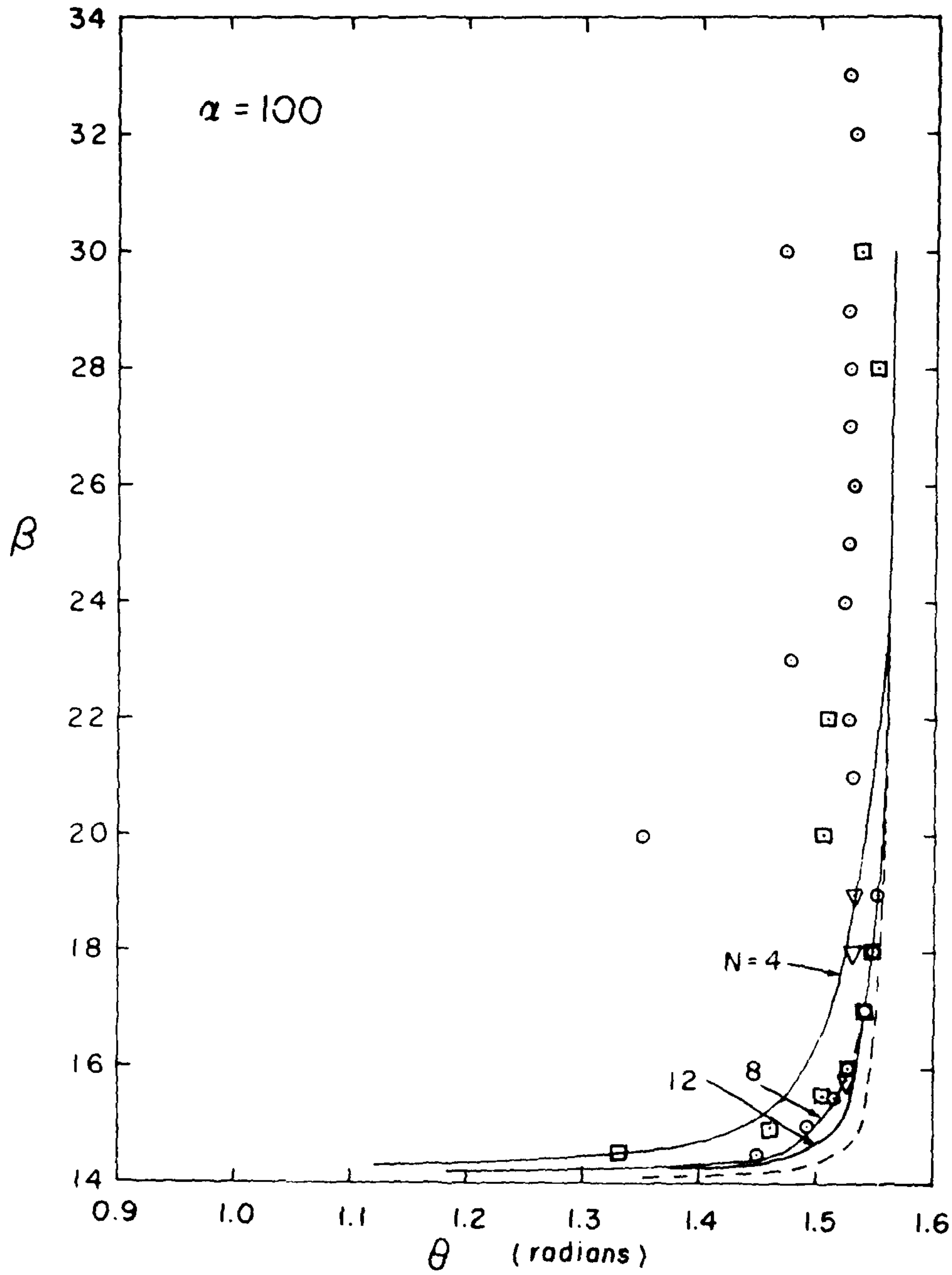

Figure 5. Separation data for α = 100 and five values of N. Solid curves N=4, 8, 12; circles N=1, squares N=2, triangles N=4; dashed curve, thin sheath limit